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Mishap Data Evaluation of Current Naval Aircraft 1987 - 1996

by

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Naval Air Warfare Center Weapons Division

FOREWORD

This report documents a study of U.S. Naval aircraft mishap data from 1987 to 1996 and, based on this study, describes those areas involving aircraft and aircrew safety systems that, with technological improvement, would most lower the mishap/injury/lethality rates of the subject aircraft and crewmembers. This effort was conducted at the Naval Air Warfare Center Weapons Division (NAWCWPNS), China Lake, Calif., by the Crew Systems Department and was sponsored by Dr. James Sheehy, Naval Air Systems Command.

This report was reviewed for technical accuracy by Mr. Bruce Trenholm, NAWCWPNS, China Lake, and Mr. John Quartuccio, Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, Md.

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13. ABSTRACT *(Maximum 200 words)*

(U) This report documents a study of U.S. Naval mishap data from January 1987 to September 1996 involving F/A-18A,B,C,D; AV-8B/TAV-8B; F-14A,B,C,D; EA-6B; T-45; T-2; S-3; and TA-4 aircraft. The study was conducted to determine which technological improvements in aircraft and aircrew safety systems might reduce the mishap/injury/lethality rates of the subject aircraft and crewmembers.

(U) Data were first sorted into aircraft categories, including aircraft lost per year by platform and mishaps per 100,000 flight hours by year and by platform. The crewmembers involved were then sorted into injury categories. For those crewmembers in the categories of fatality, permanent total disability, permanent partial disability, and major injury, the data were sorted into eject/no eject categories and then into technology categories that may have prevented the fatality or injury, first for the entire group and then for only those crewmembers who ejected.

(U) The results of this study indicate that 268 of the aircraft listed above have been lost in the 10 years studied. These mishaps involved 416 crewmembers, 192 (46.2%) of which were killed, disabled, or received a major injury. Of these 192 crewmembers, the largest number of fatalities and injuries (83 crewmembers (43.2%)) may have been eliminated if an automatic ejection system were available. One hundred twenty-three (64%) of these 192 crewmembers were known to have ejected, and of these, 41 (33.3%) may have been helped if an improved propulsion system were available. Thirty-three (26.8%) of the 123 would have been helped with an improved restraint system, while 30 (24.4%) would have been helped with an optimized parachute system. It should be noted that each crewmember may have been helped by improvements in more than one technology category; therefore the numbers do not add up to 100%.

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Ground proximity warning
Improved restraint
Injury classification
Midair collision alert system
NAMED
Naval Aviation Mishap Experience Database
Naval mishap data
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ABBREVIATIONS

DOD	Department of Defense
FM	flight mishap
Fourth Gen	Fourth Generation Escape System Technologies Demonstration Program
GLOC	*g*-induced loss of consciousness
JAG	Judge Advocate General
NAMED	Naval Aviation Mishap Experience Database
NAWCWPNS	Naval Air Warfare Center Weapons Division, China Lake, Calif.
SA	situational awareness
TVC	thrust vector control

INTRODUCTION

A study of U.S. Naval mishap data was conducted to determine which technological improvements in aircraft and aircrew safety systems might reduce the mishap/injury/lethality rates of the subject aircraft and crewmembers. The aircraft evaluated were those currently being flown and will be in use in the near future, including F/A-18A,B,C,D; AV-8B/TAV-8B; F-14A,B,C,D; EA-6B; T-45; T-2; S-3; and TA-4.

Source of Data

Data from January 1987 to September 1996 were used in this study. The information for the aircraft involved in mishaps during this period was obtained from the Naval aircraft mishap reports, the Naval Safety Center, the Naval Aviation Mishap Experience Database (NAMED), and the Judge Advocate General (JAG) mishap files. The use of multiple sources of information helped in verification of some of the data for evaluation of the impact of technology improvements. Pertinent information from each of these mishaps was entered into a database.

Data Analysis

Once the database was compiled, the information was sorted by year, platform, injury category, ejection status, and technology improvement category. The platform-related analysis is presented first, followed by the crewmember-related analysis.

Platform Analysis

During the 10 years studied, 268 of the aircraft listed above were involved in Class A flight mishaps. The following definitions from Reference 1, page 4-8, apply:

a. Flight Mishap (FM). Those mishaps in which there was $10,000 or greater DOD [Department of Defense] aircraft damage or loss of a DOD aircraft, and intent for flight for DOD aircraft existed at the time of the mishap. Other property damage or injury or death may or may not have occurred.

b. Class A Severity. A mishap in which the total cost of property damage (including all aircraft damage) is $1,000,000 or greater; or a Naval aircraft is destroyed or missing; or any fatality or permanent total disability occurs with direct involvement of Naval aircraft.

A breakdown of the aircraft lost per year and totals are shown in Table 1, and totals are shown graphically in Figure 1.

TABLE 1. Naval Aircraft Lost Per Year by Platform.

Platform	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996*	Total
T-45	0	0	0	0	0	1	0	2	0	1	4
TAV-8B	0	0	2	1	0	0	0	0	1	0	4
S-3	1	1	2	0	1	2	0	0	1	1	9
EA-6B	2	1	1	1	0	2	1	2	0	2	12
T-2	1	1	6	0	2	3	0	3	0	0	16
TA-4	5	3	6	3	3	2	1	0	0	0	23
AV-8B	4	5	3	10	5	8	4	4	5	5	53
F-14	7	7	6	3	3	6	9	6	7	5	59
F/A-18	11	5	8	8	15	13	7	4	8	9	88
Total	31	23	34	26	29	37	22	21	22	23	268

*Includes January through September data.

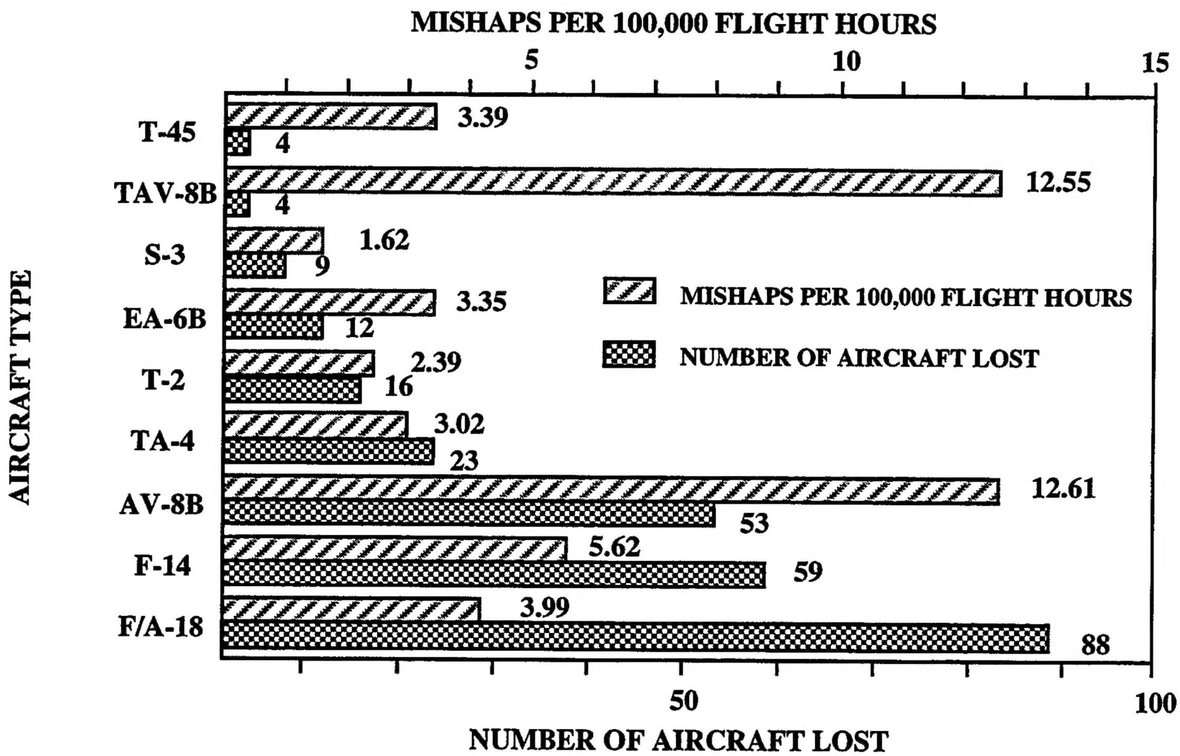

FIGURE 1. Mishaps per 100,000 Flight Hours and Total Aircraft Lost By Platform.

A useful index to compare platform safety records is the mishaps-per-100,000-flight-hours number. This number allows a more equitable comparison between frequently flown and seldom flown aircraft. A breakdown of mishaps per 100,000 flight hours per year and averaged over the 10 years studied are shown in Table 2 and graphically in Figure 2. Note that the 10-year average is not an average of those numbers shown; if a platform had no mishaps in a particular year, that year would show zero mishaps per 100,000 flight hours, even though the flight hours would add to the total hours for the 10-year period. In the same manner, if a platform had 1 mishap but only 525 flight hours (as is the case for the T-45 in 1992) the mishaps per 100,000 flight hours results in a very large number, which drops significantly when averaged over the total flight hours in the 10-year period. Thus the 10-year numbers more accurately reflect the safety records of the platforms.

TABLE 2. Mishaps per 100,000 Flight Hours by Year and by Platform.

Platform	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996*	Avg
T-45	0	0	0	0	0	190.5**	0	5.58	0	3.22	3.39
TAV-8B	0	0	68.89	27.15	0	0	0	0	28.75	0	12.55
S-3	1.40	1.53	3.28	0	1.70	4.00	0	0	1.96	2.57	1.62
EA-6B	5.74	2.91	2.85	2.59	0	5.04	2.50	6.11	0	7.83	3.35
T-2	1.08	1.20	6.06	0	3.18	5.82	0	6.73	0	0	2.39
TA-4	4.19	2.65	5.52	2.01	3.51	2.77	2.10	0	0	0	3.02
AV-8B	16.15	13.46	7.22	24.06	9.37	14.45	8.42	9.04	11.19	17.18	12.61
F-14	6.32	5.62	4.96	2.55	2.43	5.87	9.51	6.24	6.78	9.92	5.62
F/A-18	7.14	2.81	3.75	3.36	5.70	5.74	2.50	2.10	3.02	4.83	3.99
Avg	5.08	3.65	5.01	3.75	4.14	6.05	3.70	3.58	3.47	5.51	4.37

* Includes January through September data.

**Single aircraft lost in 525 flight hours.

Crewmember Analysis

In the 10 years studied, 416 crewmembers were involved in Class A flight mishaps. Crewmembers fell into the following injury categories:

A = Fatal Injury
B = Permanent Total Disability
C = Permanent Partial Disability
D = Major Injury
E = Minor Injury
F = First Aid Injury
G = No Injury

A more precise description of each injury category can be found in Appendix A of this report. Table 3 lists the 416 crewmembers by year and injury category, with the information shown graphically in Figure 2.

TABLE 3. Crewmembers Involved in Class A Flight Mishaps.

Year	Injury category					Combined	A-G,	A-D, %
	A	B	C	D	E - G	A-D	total	of A-G
1987	12	0	0	15	24	27	51	52.9
1988	14	0	0	5	20	19	39	48.7
1989	16	0	1	11	29	28	57	49.1
1990	7	0	1	6	21	14	35	40.0
1991	8	0	0	5	22	13	35	37.1
1992	20	0	1	9	27	30	57	52.6
1993	8	1	0	5	21	14	35	40.0
1994	6	0	1	4	24	11	35	31.4
1995	7	0	0	6	23	13	36	36.1
1996*	18	0	0	5	13	23	36	64.9
Total	116	1	4	71	224	192	416	46.2
% of total	27.9	0.2	1.0	17.1	53.8	46.2		

* Includes January through September data.

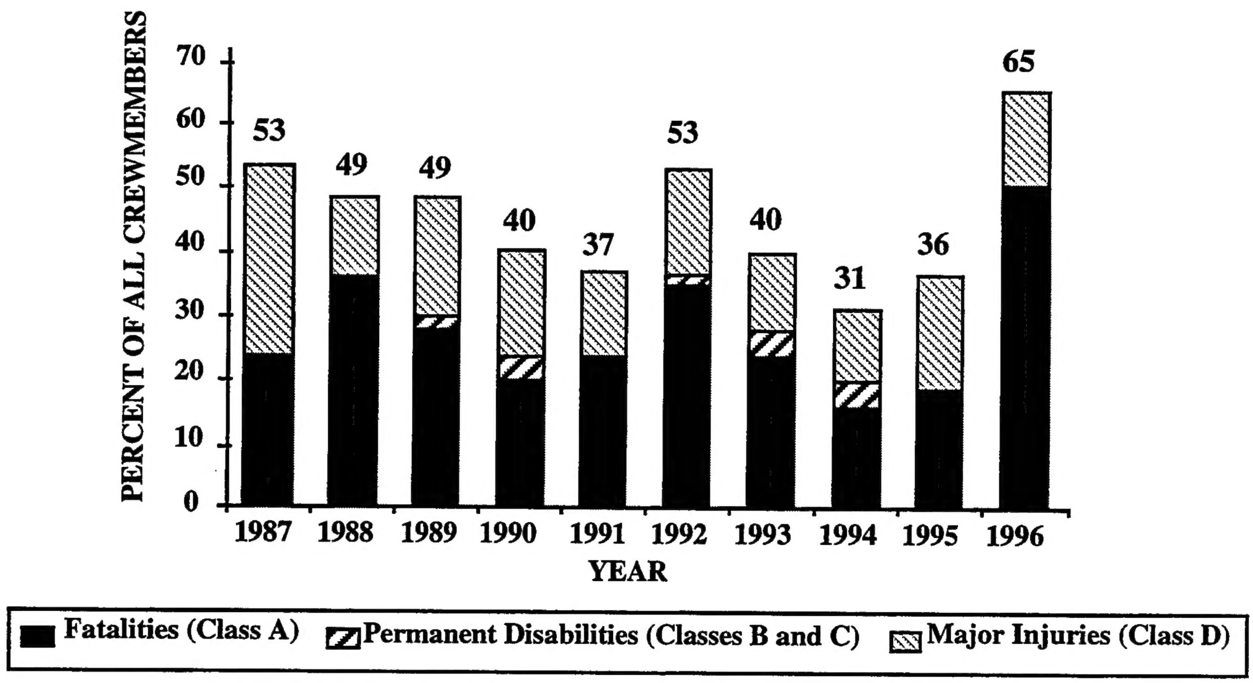

FIGURE 2: Percentage of Crewmembers By Year With A Through D Injuries (1996 Includes January through September Data).

As can be seen from Table 3, 116 (27.9%) of the 416 crewmembers involved in mishaps were killed, with an additional 76 crewmembers receiving permanent disabilities

or major injuries, for a total of 192 crewmembers (46.2%) severely injured or killed in the aircraft studied during the last 10 years.

After the data were sorted by injury category, the crewmembers in the A through D injury categories were broken down to show the percentage of crewmembers killed or severely injured by platform. These data are listed in Table 4 and shown graphically in Figure 3 (combined with aircraft lost by platform, as listed in Table 1).

TABLE 4. Percentage of Crewmembers Killed or Injured by Platform

Platform	Total crewmembers involved in mishaps (A-G injury categories)	Crewmembers in A-D injury categories	A-D % of total
T-45	4	2	50
TAV-8B	8	3	38
S-3	26	20	77
EA-6B	44	30	68
T-2	26	14	54
TA-4	37	13	35
AV-8B	53	24	45
F-14	118	36	31
F/A-18	100	50	50
Total	416	192	46

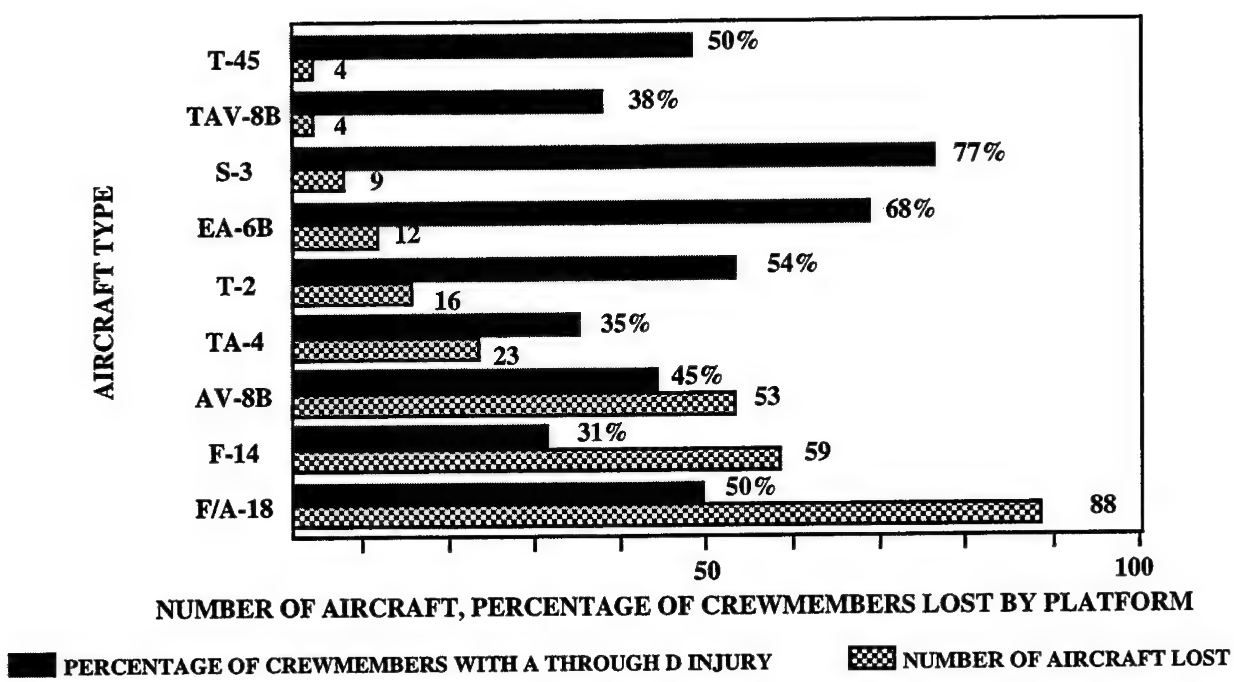

FIGURE 3. Percentage of Crewmembers in A Through D Injury Categories and Number of Aircraft Lost, by Platform.

The crewmembers in the A through D injury categories were then sorted into eject/no eject categories, shown in Table 5 and graphically in Figure 4. Because ejection status information was not available for mishaps in which the crew and aircraft were lost at sea, 11 crewmembers are in the unknown category. Crewmembers involved in midair collisions who did not eject have also been listed separately. In addition, several crewmembers were placed in the "other" category, which includes crewmembers who were able to land the aircraft but were injured during landing or while egressing from the aircraft. For those crewmembers in a multi-place aircraft, all crewmembers were counted as having ejected if a command eject was initiated, even if some of the crewmembers never left the cockpit.

TABLE 5. Ejection Initiation Breakdown of Crewmembers in A Through D Injury Categories.

Ejection status	Injury category				Total	% of all
	A	B	C	D	A-D	192 A-D
Ejected	52	0	4	67	123	64.1
No eject (midair)	13	0	0	0	13	6.8
No eject (other)	37	0	0	0	37	19.3
Unknown	11	0	0	0	11	5.7
Other	3	1	0	4	8	4.2
Total	116	1	4	71	192	100.0

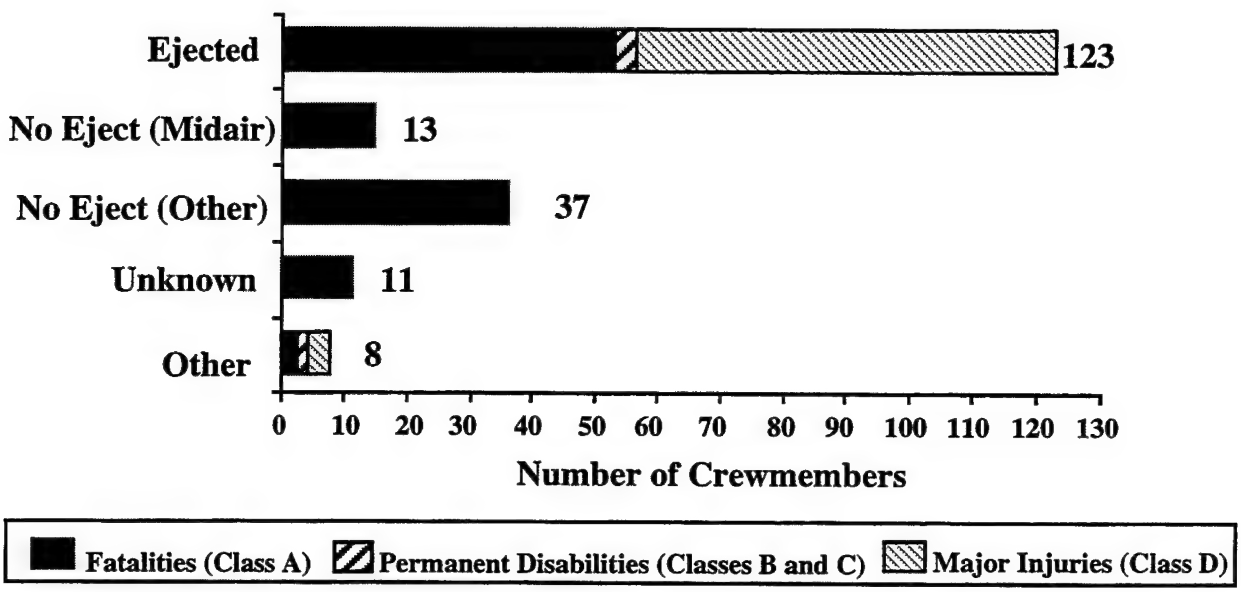

FIGURE 4. Ejection Initiation Breakdown of Crewmembers in A Through D Injury Categories.

The final phase of the data evaluation consisted of determining an area or areas of technological improvement that may have eliminated the fatal and severe injuries for each crewmember in the A through D injury categories. The determination of the technology categories was based on evaluating the aircraft's velocity, altitude, and static and dynamic orientation at the time of ejection; the crewmember's ejection status, injuries, and cause of injuries; and any other information available as to the cause of the mishap. Because computer simulation of these mishaps has not yet been done, this categorization should be considered an engineering estimate. A higher fidelity estimate using simulation tools should be the next step in analyzing the data, and would give a better idea of specific improvements that should be undertaken.

The category breakdown for all the crewmembers is shown first, followed by a breakdown of categories for only those crewmembers who attempted to eject. This helped determine the problem areas first at a system level (which would potentially involve modifications to the aircraft), and then at a seat level (which would involve modifications to seat subsystems). After a review of the mishaps, the following technology categories were developed. Because most of these areas involve technology that is not fully developed, some assumptions were made regarding their utility. These assumptions, and a brief description of the categories, are as follows:

1. **Automatic Ejection (Autoeject)**. With this technology, a device utilizing input from aircraft sensors coupled with software algorithms and a safe/arm initiation system would detect when an aircraft is going to impact terrain or other ground based objects. After a brief warning, if no corrective action is taken, this technology would eject the crewmember within the ejection seat's safe escape envelope. For this category, it was assumed that a large mass, such as the ground or sea, was detectable. This technology would not have been useful for midair collision avoidance.

2. **Ground Proximity Warning/Automatic Avoidance System**. Using the same sensing and trajectory determination technology as in no. 1 above, this system would warn the crewmember of imminent ground impact. If the warning went unheeded, this technology would take over control of the aircraft and return it to safe flight. This system would not be useful for takeoff or landing.

3. **Enhanced Seat Propulsion System**. This technology, currently undergoing testing, combines additional propulsion impulse with controlled thrust in order to give the ejection system an expanded safe operating envelope. This technology actively controls the motor thrust and moments (roll, pitch, and yaw) applied to the seat in order to enable enhanced stabilization. Also, the rocket motor burn time is increased from 0.25 second, which is standard in operational ejection seats, to 0.5 to 1.2 seconds. The Fourth Generation Escape System Technologies Demonstration Program (Fourth Gen) is a joint Navy/Air Force program that uses pintle nozzles to achieve controlled propulsion. In 1996 and 1997, the Fourth Gen system demonstrated stability at adverse attitudes (0 keas/60 degrees roll and up to 450 keas/20 degrees yaw) and stability at high speed (up to 700 keas). Other approaches include thrust vector control (TVC) through the means of a trapped ball (or gimballed) nozzle.

4. **Vertical Seeking Seat**. Using either on-board sensors or an interface to aircraft sensors indicating attitude at ejection, the vertical seeking seat would steer the crewmember into a vertical climb following ejection, which would improve the safe escape envelope even more than the enhanced seat propulsion system described above.

This system would increase rocket burn time to the range of 1.0 to 1.8 seconds. This capability was demonstrated by both the Fourth Gen system in 1996 and 1997 and the Maximum Performance Ejection Seat in 1978 (Reference 2). This allows ample trajectory compensating ability, but with an increased weight penalty.

5. **Heat Resistant Parachute**. To prevent heat from a fireball from melting the nylon material of the parachute, a heat-resistant material would be substituted. However, this may affect its strength and elongation.

6. **Reserve Parachute With Automatic Opener**. A reserve parachute would be available in case of main parachute failure. An automatic opening device would deploy the reserve parachute if the crewmember was unconscious or disoriented.

7. **Improved Performance Parachute**. This technology would include increasing the parachute's strength, lowering opening forces during high speed ejections, lowering the descent rate, or increasing the deployment speed during low speed ejections.

8. **Improved Restraint/Windblast Protection During Ejection**. This technology would involve improvements to the body positioning system, improvements to a limb retraction system, or development of a windblast protection system.

9. **Steerable, High Glide Parachute**. By using a steerable high glide parachute with a horizontal velocity to vertical velocity ratio between 2 and 3, an ejected crewmember with sufficient altitude may be able to fly away from dangers such as fire or enemy troops, or fly toward the carrier deck or recovery teams.

10. **Improved Survival Gear**. This technology would include improvements to survival gear to better support crewmember post-ejection needs (such as a better raft, radio, etc.).

11. **Midair Collision Alert System**. This technology would involve using aircraft sensors to alert the crewmember of imminent collision with another aircraft. This may involve using an active or passive detecting system that, if active, could be deselected during combat.

12. **Improved Inter-Seat Timing**. This technology would involve improvements to the inter-seat sequencing of multi-place aircraft during a command eject, in an effort to shorten the time delay between the ejection of the first and last seats.

13. **Others**. This category is for miscellaneous improvements to the escape system, such as lower rocket forces and improved harness fit.

14. **Insufficient Data**. As several of the mishaps involved aircraft lost at sea, very little information is available.

15. **Equipment Malfunction/Human Error**. This category documents those cases in which a technological improvement is not applicable, such as an equipment malfunction or a crewmember not attached to the parachute at ejection.

Each crewmember in the A through D injury categories was assigned at least one technology category (with many having more than one), based on the nature of the

mishap and injuries. For example, many of the mishaps that occurred because the pilot lost situational awareness (SA) were assigned both categories 1 and 2 because a ground proximity warning may have alerted the pilot and if not, an auto-avoidance system may have been able to take over control of the aircraft until the pilot regained SA. If the auto-avoidance could not respond quickly enough, or if the aircraft was not controllable, an autoeject system may have eliminated or reduced the level of injury. In some cases, injuries were sustained due to different causes and therefore several categories are listed.

A breakdown of individual technology categories for all crewmembers in the A through D injury categories is shown in Appendix B. Table 6 and Figure 5 represent a combining of similar technology categories to represent a systems approach to the data analysis. Because some crewmembers were assigned more than one category, the total number of fatalities and injuries assigned for all the categories **does not** add up to the total of 192 crewmembers. In addition, the numbers shown in the combination of categories do not reflect an addition of the component individual categories, as a single crewmember may be listed in each of the pre-combined individual categories but is counted only once in the combination.

TABLE 6. Combined Technology Categories and A, B, C, and D Injury Classes; All Crewmembers (Ejected and Non-Ejected).

Category no.	Category combination	A	B	C	D	Total, A-D	% of all 192 A-D
1 or 2	Autoeject, ground proximity warning/auto-avoidance	84	1	0	4	89	46.4
3 or 4	Enhanced/vertical seeking seat	30	0	1	10	41	21.4
8	Improved restraint/windblast protection	3	0	2	29	34	17.7
5, 7, or 9	Optimized parachute	4	0	2	24	30	15.6
11	Midair collision alert system	13	0	1	2	16	8.3

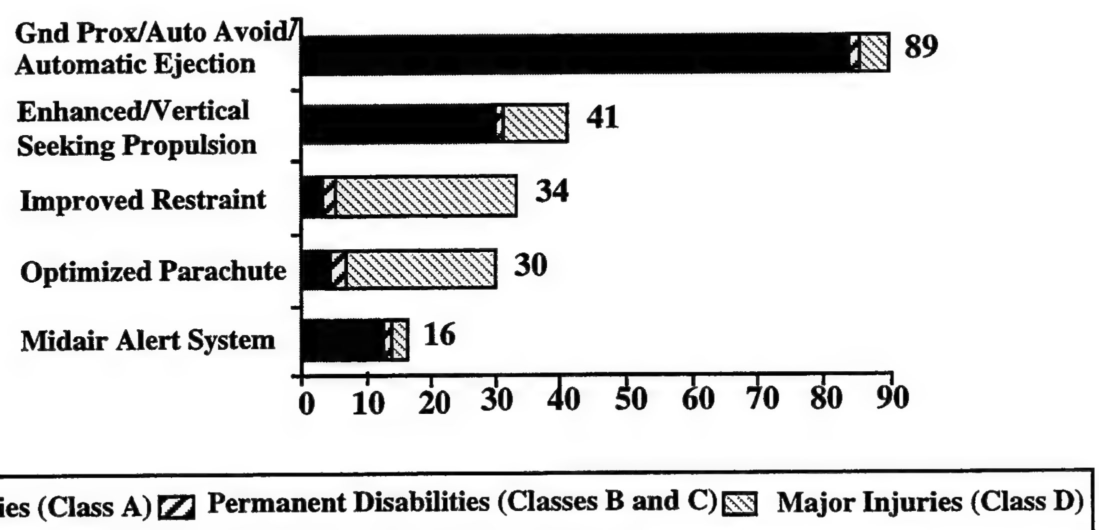

FIGURE 5. Combined Technology Categories and A, B, C, and D Injury Classes; All Crewmembers (Ejected and Non-Ejected).

Appendix C is the breakdown of individual categories for those crewmembers who attempted to eject. Again, following the individual breakdown, like categories were combined to show improvement areas at a system level. This combination of categories is listed in Table 7 and shown graphically in Figure 6. As before, due to multiple categories assigned to most crewmembers, the numbers will not add up to the total of 123 crewmembers who ejected. In addition, the numbers shown in the combination of categories do not reflect an addition of the component individual categories, as a single crewmember may be listed in each of the pre-combined individual categories but is counted only once in the combination.

TABLE 7. Combined Technology Categories and A, B, C, and D Injury Classes; Ejected Crewmembers Only.

Category no.	Category combination	A	B	C	D	Total, A-D	% of all 123 ejected, A-D
3 or 4	Enhanced/vertical seeking seat	30	0	1	10	41	33.3
1 or 2	Autoeject, ground proximity warning/auto-avoidance	36	0	0	4	40	32.5
8	Improved restraint during ejection	3	0	2	28	33	26.8
5, 7, or 9	Optimized parachute	4	0	2	24	30	24.4

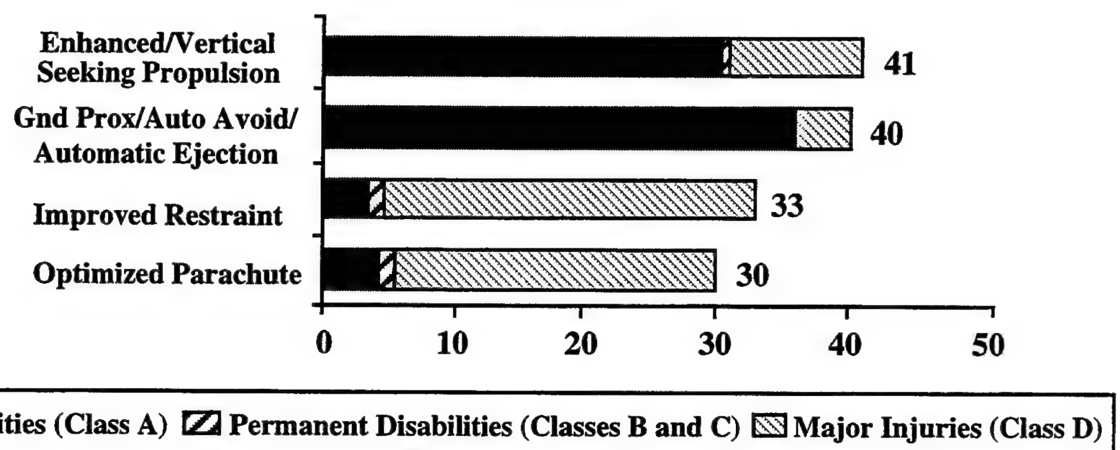

FIGURE 6. Combined Technology Categories and A, B, C, and D Injury Classes; Ejected Crewmembers Only.

RESULTS OF ANALYSIS

Ground Proximity Warning / Auto-Avoidance / Autoeject System

Figure 4 shows that 50 (43.1%) of the 116 fatally injured crewmembers never ejected. This does not include those crewmembers in multi-place aircraft who never made it out of the aircraft, or those whose ejection status is unknown. Figure 5 shows that 84 (72.4%) of the 116 fatalities, and 89 (46.4%) of the 192 crewmembers in the A through D injury categories may have survived or had reduced potential for injury if either an autoeject or a ground proximity warning/auto-avoidance system were available. Even for those crewmembers who did eject, 36 (69%) of the 52 ejected fatalities and 40 (32.5%) of the 123 crewmembers receiving A through D injuries may have been helped if such a system were available to warn of imminent ground collision, to steer away from the ground, or to initiate an earlier ejection. At the high speeds being flown, a split second wasted in reaction time could mean the difference between life and death.

Enhanced / Vertical Seeking Propulsion

Thirty (25.9%) of the 116 fatalities and 41 (21.4%) of the 192 crewmembers involved in A through D injuries may have survived or had reduced potential for injury if an enhanced or vertical seeking propulsion system had been available. This number becomes more significant when compared to the total number of crewmembers who actually ejected: these 30 fatalities represent 57.7% of the 52 ejected fatalities, while the 41 A through D injured crewmembers represent 33.3% of the 123 A through D injured crewmembers who did eject, indicating an obvious need for improved propulsion capability. This will be even more obvious if more crewmembers get the chance to eject with an autoeject system.

Improved Restraint

Another category that involved a large number of fatalities or major injuries was the need for improved restraint in the ejection seat and windblast protection during ejection. Of the 192 crewmembers sustaining A through D injuries, 34 (17.7%) may have been helped if they had been restrained more effectively or been better protected from windblast during ejection. Many of these were limb flail injuries received during ejection, but some were caused by the crewmember being thrown out of position because of aircraft dynamics prior to ejection.

Optimized Parachute

The mishap data indicate that improvements to the parachute may have reduced the potential for fatality or injury for 30 (15.6%) of the 192 crewmembers, which is 24.4% of the 123 crewmembers who ejected. These improvements would need to include: (1) a selectable maneuverable gliding capability (15 crewmembers affected), (2) a lower opening shock/controlled opening (11 crewmembers affected), (3) a lower rate of descent (4 crewmembers affected), and (4) heat-resistant material (2 crewmembers affected). As with propulsion, the shortcomings of the parachute system will become more evident if an autoeject system is implemented to give more crewmembers a chance to escape.

Midair Collision Alert System

A large number of injuries and fatalities (16 of the 192 crewmembers) occurred because of midair collisions. Thirteen of the 16 crewmembers never ejected and were killed. Some type of midair collision alert system may have prevented these mishaps.

CONCLUSIONS

After evaluating the mishap data from the last 10 years, the major problem confronting Naval aviation in regard to saving the lives and careers of its crewmembers on a total system level seems to be getting the crewmembers out of unrecoverable aircraft. The problems associated with the ejection seat and subsystems are minor compared to the overwhelming problem of crewmembers who never eject at all. On a seat level, however, when evaluating those crewmembers who did eject, the areas of propulsion, restraint/windblast protection, and parachute recovery all ranked high in potential number of lives saved/injuries reduced with technology investment.

These findings are not new, as indicated in several previously published reports. Walter Peck, LME Inc., reviewed February 1979 through February 1993 Air Force fatalities and 1981 through 1991 Navy fatalities to determine the relative benefits of automatic ejection, automatic aircraft flight control (auto-avoidance), and improved trajectory control of the ejection seat (Reference 3). His findings indicate that an auto-eject system may have made a difference in 73 (86.9%) of 84 Air Force fatalities, an auto-avoidance system may have helped 56 (66.7%) of the 84 Air Force crewmembers, and improved trajectory control of the ejection seat may have helped 7 (8.3%) of the 84. For the Navy, an auto-eject system may have helped 156 (76.5%) of 204 crewmembers, while an auto-avoidance system may have made a difference in 124 (60.8%) of the 204 fatalities, and improved trajectory control of the seat may have helped 36 (17.6%) of the 204.

William Pickl, Wright Patterson Air Force Base Aircrew Escape Group, also performed a study of Air Force and Navy ejection attempts between 1978 and 1990 and concluded that between 54 and 81% of the out-of-envelope ejection fatalities may have been prevented with improved trajectory control of the ejection seat (Reference 4).

Art Karrer, Naval Air Warfare Center Weapons Division (NAWCWPNS), China Lake, Calif., published a report in which 967 non-combat ejection reports from 1976 through 1989 were analyzed (Reference 5). Among the conclusions of this report was a need for development of an automatic ejection system, vertical seeking escape system, and high glide recovery system.

Bruce Trenholm, NAWCWPNS, China Lake, published a report in which 273 mishaps from 1987 through 1993 were analyzed to determine the principal causes of crewmember fatalities and serious injuries (Reference 6). Again, among the conclusions of this report were a need for a ground proximity warning device; automatic ejection system; vertical seeking ejection system; and high glide, fire retardant recovery system.

As aircraft envelopes expand and the workload on the crewmembers increases with new and more complex weapons systems, the trend of crewmembers losing SA or

sustaining *g*-induced loss of consciousness (GLOC) will probably continue. Every effort should be made to reduce the workload on the crewmembers, including the critical decision of when to eject. The Russian Yak-38 has used an automatic ejection system for over 15 years and, although not initially well received by crewmembers, is now referred to as the "guardian angel," having recovered 21 of 22 crewmembers to date (the fatality resulted from the crewmember switching off the system).

Improvements in propulsion and restraint and in the parachute are also indicated and may be made more obvious when more crewmembers actually get the opportunity to use the ejection seat.

Upon reviewing the mishap data, it became clear that by far the best way to reduce the financial and emotional impact of aircraft mishaps is to prevent them in the first place. Some of the technology areas listed above, including Ground Proximity Warning, Ground Collision Avoidance, and Midair Collision Alert systems, would save not only the crewmembers but also the aircraft. These areas are, therefore, the highest payoff areas listed in this study. One of these, the Ground Proximity Warning System, is now being implemented in the F/A-18 and AV-8B aircraft and, although this is a passive warning system as opposed to an active ground collision avoidance system, it should make a noticeable difference in future mishap statistics.

Unfortunately, mishaps will continue to occur, and although all crewmembers will not be saved from all mishaps, significant development effort should be expended in the areas providing significant benefit to crewmember survival.

REFERENCES

1. Naval Safety Center. *Naval Aviation Safety Program.* Norfolk, Va., NSC, 28 August 1989. (OPNAVINST 3750.6Q, Change 1 of 27 March 1991; publication UNCLASSIFIED.)

2. Naval Air Warfare Center Weapons Division. *Development and Demonstration of a Seat Steering And Control System for the Maximum Performance Ejection Seat (MPES),* by W. J. Stone and D. L. Bishop. China Lake, Calif., NAWCWPNS, May 1980. (NAWCWPNS TP 6128, publication UNCLASSIFIED.)

3. LME, Inc. *Automatic Ejection/Automatic Flight Control Study*, by Walter Peck. Fletcher, N.C., LME, December 1995. (LME white paper, paper UNCLASSIFIED.)

4. Wright Patterson Air Force Base. Summary of a Review of Ejection Attempts (78-90), by William G. Pickl. Dayton, Ohio, WP AFB, March 1992. (Memorandum UNCLASSIFIED.)

5. Naval Air Warfare Center Weapons Division. *Data Trend Analysis Report for Navy Ejections (1976 Through 1989)*, by Art Karrer. China Lake, Calif., NAWCWPNS, March 1993. (NAWCWPNS TP 8111, publication UNCLASSIFIED.)

6. ______. *Major Causes of Mishap-Related Fatalities and Major Injuries 1987 - 1993*, by Bruce Trenholm. China Lake, Calif., NAWCWPNS, May 1994. (NAWCWPNS TP 8190, publication UNCLASSIFIED.)

Appendix A

INJURY CLASSIFICATION

(TAKEN FROM OPNAVINST 3750.6, CHAPTER 4)

(This appendix is reproduced in facsimile.)

Class A

Fatal Injury. An injury which results in death from a mishap or the complications arising therefrom, regardless of the length of time intervening between the mishap and a subsequent death.

Class B

Permanent Total Disability. Any nonfatal injury which, in the opinion of competent medical authority, permanently and totally incapacitates a person to the extent that they cannot follow any gainful occupation. In addition, the loss of, or the loss of use, of both hands, or both feet, or both eyes, or a combination of any of those body parts as a result of a single mishap will be considered as a permanent total disability.

Class C

Permanent Partial Disability. An injury which does not result in death or permanent total disability but, in the opinion of competent medical authority, results in permanent impairment or loss of any part of the body, the loss of the great toe, the thumb, or an unrepairable inguinal hernia, with the following exceptions:

(1) Teeth
(2) The four smaller toes
(3) Distal phalanx of any finger
(4) Distal two phalanges of the little finger
(5) Repairable hernia
(6) Hair, skin, nails, or any subcutaneous tissue

Class D

Major Injury. A nonfatal injury which does not result in death, permanent total disability or permanent partial disability, but which results in five or more lost workdays and requires admission to a hospital or quarters or a combination of both, for five or more days. It also includes any of the following regardless of hospital status:

(a) Unconsciousness for more than five minutes due to head trauma
(b) Fracture of any bone, except simple fracture of the nose or phalanges
(c) Traumatic dislocation of major joints or internal derangement of the knee
(d) Moderate to severe lacerations resulting in severe hemorrhage or requiring extensive surgical repair
(e) Injury to any internal organ
(f) Any third degree burns, or any first or second degree burns (including sunburn) over five percent of the body surface

Class E

Minor Injury. An injury less than major which results in one or more but less than five lost workdays.

Class F

First Aid Injury. An injury requiring minimal treatment(s) or no treatment and not resulting in a lost workday.

Class G

No Injury. Also includes transient unconsciousness due to hypoxia, hyperventilation, "G" forces, etc.

Appendix B

TECHNOLOGY BREAKDOWN OF FATALLY AND SEVERELY INJURED CREWMEMBERS (EJECTED AND NON-EJECTED)

Table B-1 is a breakdown of individual technology categories that may have eliminated the mishap or reduced the injury potential for those crewmembers in the A through D injury categories. Because each crewmember was assigned to at least one and usually more than one technology category, the number of fatalities and injuries assigned to each technology category will not add up to the total of 192 crewmembers. Figure B-1 shows the same information graphically.

TABLE B-1. Breakdown of Technology Categories and A, B, C, and D Injury Classes; All Crewmembers (Ejected and Non-Ejected).

Cate-gory no.	Technology category	A	B	C	D	Total A-D	% of all 192 A-D
1	Automatic ejection	81	1	0	1	83	43.2
2	Ground prox. warning/auto avoid	60	0	0	4	64	33.3
3	Enhanced seat propulsion	19	0	1	7	27	14.1
4	Vertical seeking seat	12	0	0	3	15	7.8
5	Heat resistant parachute	2	0	0	0	2	1.0
6	Reserve parachute with auto. opener	0	0	0	1	1	0.5
7	Improved performance parachute	2	0	0	14	16	8.3
8	Improved restraint/windblast protection	3	0	2	29	34	17.7
9	Steerable, high glide parachute	2	0	2	11	15	7.8
10	Improved survival gear	0	0	0	2	2	1.0
11	Midair collision alert system	13	0	1	2	16	8.3
12	Improved inter-seat timing	5	0	0	1	6	3.1
13	Other	2	0	0	11	13	6.8
14	Insufficient data	18	0	0	5	23	12.0
15	Equipment malfunction/human error	10	0	0	12	22	11.5

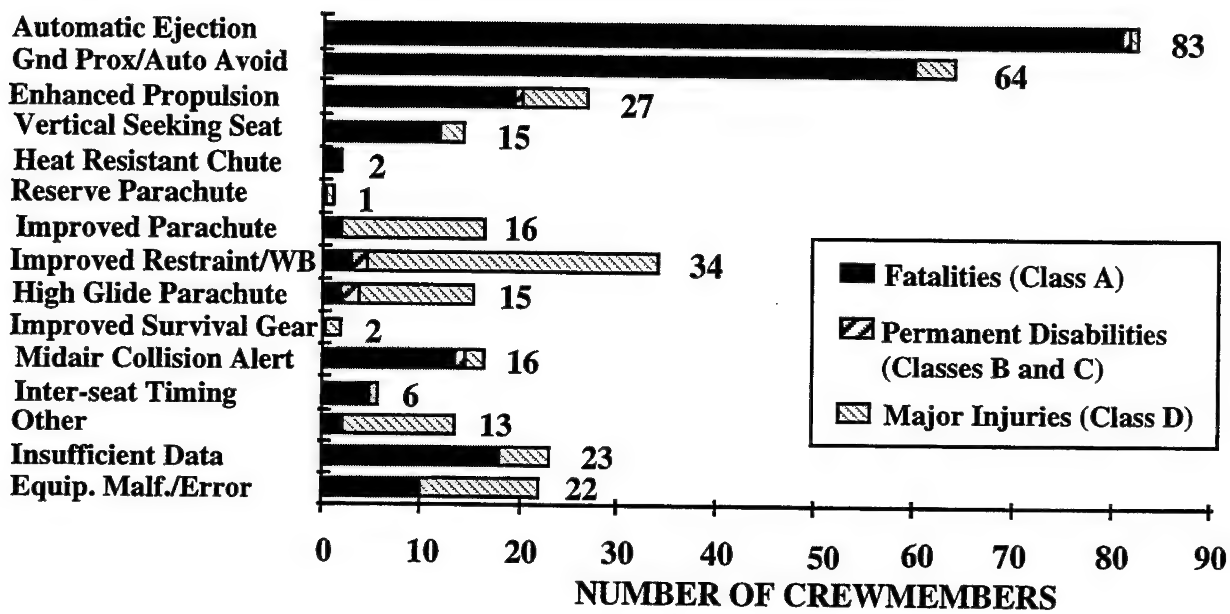

FIGURE B-1. Breakdown of Technology Categories and A, B, C, and D Injury Classes; All Crewmembers (Ejected and Non-Ejected).

Appendix C

TECHNOLOGY BREAKDOWN OF FATALLY AND SEVERELY INJURED CREWMEMBERS (EJECTED ONLY)

Table C-1 is a breakdown of individual technology categories that may have eliminated the mishap or reduced the injury potential for those crewmembers in the A through D injury categories who attempted to eject. Because each crewmember was assigned to at least one and usually more than one technology category, the number of fatalities and injuries assigned to each technology category will not add up to the total of 123 crewmembers that ejected. Figure C-1 shows the same information graphically.

TABLE C-1. Breakdown of Technology Categories and A, B, C, and D Injury Classes; Ejected Crewmembers Only.

Category no.	Technology category	A	B	C	D	Total A-D	% of all 123 ejected A-D
1	Automatic ejection	35	0	0	1	36	29.3
2	Ground prox. warning/auto avoid	16	0	0	4	20	16.3
3	Enhanced seat propulsion	19	0	1	7	27	22.0
4	Vertical seeking seat	12	0	0	3	15	12.2
5	Heat resistant parachute	2	0	0	0	2	1.6
6	Reserve parachute with auto opener	0	0	0	1	1	0.8
7	Improved performance parachute	2	0	0	14	16	13.0
8	Improved restraint/windblast protection	3	0	2	28	33	26.8
9	Steerable, high glide parachute	2	0	2	11	15	12.2
10	Improved survival gear	0	0	0	2	2	1.6
11	Midair collision alert system	0	0	1	2	3	2.4
12	Improved inter-seat timing	5	0	0	1	6	4.9
13	Other	2	0	0	11	13	10.6
14	Insufficient data	1	0	0	4	5	4.1
15	Equipment malfunction/human error	7	0	0	9	16	13.0

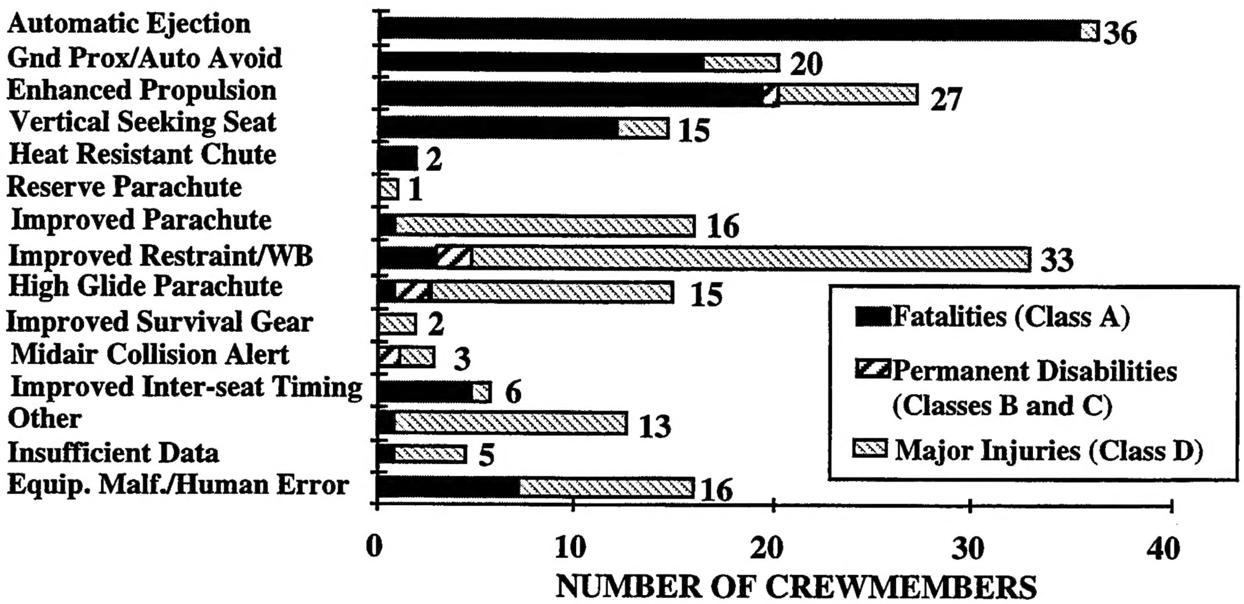

FIGURE C-1. Breakdown of Technology Categories and A, B, C, and D Injury Classes; Ejected Crewmembers Only.

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